Guidelines For Preliminary Design Of Bridges And Culverts

Appendix A

Culverts

Iowa Runoff Chart

In the 1950's, the Iowa State Highway Commission (now Iowa DOT) adapted Bureau of Public Roads' Chart 1021.1, "Highway Drainage Manual", 1950. (BPR's chart was adapted from original work performed by W.D. Potter, "Surface Runoff from Small Agricultural Watersheds," Research Report No. 11-B, (Illinois) Highway Research Board, 1950.) The Iowa Runoff Chart has been widely used by IDOT and the counties since then.

The chart is self-explanatory. However, its use does require the exercise of judgement in selecting the land use and land slope factors. It can be used for rural watersheds draining up to 400 hectares (1000 acres).

The following is intended to aid that judgement:

1. Very Hilly Land---is best typified by the bluffs bordering the Mississippi and the Missouri Rivers. This terrain is practically mountainous (for Iowa) in character. Small areas of very hilly land can be found in all parts of the state. Typically, they can be found near the edge of the flood plains of the major rivers.

2. Hilly Land---is best typified by the rolling hills of south central Iowa. Interstate 35 in Clarke and Warren Counties traverses many hilly watersheds. Small areas of hilly land can be found in all parts of the state.

3. Rolling Land---is best typified by the more gently rolling farm lands of central Iowa. Interstate 80 in Cass and Adair Counties traverses many rolling watersheds. Small areas of rolling land can be found in all parts of the state.

4. Flat Land---is best typified by the farm lands of the north central part of the state. U.S. 69 traverses many flat watersheds in Hamilton and Wright Counties. Small areas of flat land can be found in all areas of the state.

5. Very Flat Land---is best typified by the Missouri River flood plain. Interstate 29 is located on this type of land for most of its length. Much of Dickinson, Emmet, Kossuth, Winnebago and Palo Alto Counties are also in this classification. Small areas of very flat land can be found in all parts of the state.

Use the Iowa Runoff Chart only for rural watersheds and the limitations of drainage areas listed below. The equations were developed by finding the best statistical fit to the curve on the Runoff Chart.

English equation

For drainage areas, $2 < A < 1000$ acres
$Q_{design} = LF \times FF \times Q$, where $Q = 8.124\, A^{0.739}$
Q is in ft^3/sec
A is in acres

Metric equation

For drainage areas, $1 < A < 400$ hectares
$Q_{design} = LF \times FF \times Q$, where $Q = 0.446\, A^{0.740}$
Q is in m^3/sec
A is in hectares

Frequency Factor (FF)

Frequency, years	5	10	25	50	100
Factor, FF	0.5	0.7	0.8	1.0	1.2

Land Use and Slope Description (LF)

Land Use	Slope Description				
	Very Hilly	Hilly	Rolling	Flat	Very Flat (no ponds)
Mixed Cover	1.0	0.8	0.6	0.4	0.2
Permanent Pasture	0.6	0.5	0.4	0.2	0.1
Permanent Woods	0.3	0.25	0.2	0.1	0.05

Design Guidelines for Slope Tapered Box Culverts

The purpose of slope tapered box culverts is to reduce construction costs by using a smaller barrel but still providing acceptable hydraulic capacity and upstream headwater. These special inlets have been used in Iowa and across the country since the 1950's or earlier. The design of these inlets includes rigid hydraulic design and good construction practice.

The culvert site normally will meet two basic requirements to qualify for a tapered inlet. The first is that the additional design costs are offset by the reduction in construction costs. The second is that the site must have enough fall for the design to perform properly, typically at least six to eight feet.

The culvert inlet is made large enough to keep the depth of water at the entrance within allowable limits. The slope taper section Afunnels≅ the water down a steep slope as the culvert width decreases. The barrel section is designed to flow nearly full when carrying the design discharge. Generally the outlet has a flume and basin for energy dissipation.

Design Steps

There are five basic steps for the hydraulic design a box culvert with a slope tapered inlet.

1. Determine the design discharge. The Iowa Runoff Chart shall be used for rural watersheds draining 1000 acres (400 hectares) or less.
2. Determine the allowable depth of water at the inlet. Typically, the Iowa DOT allows one foot (0.3 m) of water above the top of the inlet.
3. Select an inlet size that results in a flow depth less than or equal to the allowable. Inlet control nomographs from FHWA=s AHydraulic Design of Highway Culverts≅, HDS No. 5, can be used for this.
4. Select a barrel size and slope that results in the barrel flowing less than full. The barrel height should be the same as the inlet, while the barrel width should generally be no less than 50 to 60% of the inlet width. Select a slope steep enough to maintain supercritical flow. Charts in FHWA=s ADesign Charts for Open-Channel Flow≅, HDS No. 3, have been developed from Manning=s equation and can be used to select the appropriate slope.
5. Determine the drop and length of the slope tapered section. The minimum drop needed is the specific energy at the inlet (H_1) minus the specific energy at the barrel (H_2) plus energy losses (H_L). Specific energy is the depth plus velocity head at a given location.

The following guidelines, charts and worksheets (English and metric units) are provided to assist in the hydraulic design.

When the inlet will be raised significantly to create a pond, geotechnical concerns must be considered to ensure that seepage through the embankment is not excessive.

General Guidelines

1. HW from inlet control charts for proposed inlet size, no greater than D + 2 ft. (D + 0.6 m.)
2. The height (D) of the structure does not change.
3. Calculated Z may be rounded to the next higher increment as described below.
   Minimum Z = 3 ft.(0.9 m.)

4. Taper can be designed by using the RCB standard reinforced steel pattern of inlet size for the entire length of the taper and varying the length of the transverse steel.
5. The barrel outlet flowline is usually set at least ½ (D) above streambed. This prevents the barrel from "drowning out".
6. The outlet usually has a flume with a basin that is buried 4 ft. to 6 ft. (1.2 m. to 1.8 m.) below streambed, to help dissipate energy.
7. The barrel slope (S_o) should generally be 1.5% or steeper in order to maintain supercritical flow and the maximum flow depth of 0.9D in the barrel. (See "Design Charts for Open Channel flow", HDS No. 3, FHWA, to determine specific flow depths for various slopes.)
8. An attempt should be made to design barrel sizes to conform with standard RCB sizes. This may mean starting with a "wide" non-standard inlet.
9. Assume energy loss, H_L = 0.2 ft. (0.1 m.) for all cases.

Guidelines for single RCBs

1. Use drop rate (L/Z) of approximately 3:1.
2. Ratio of barrel width to inlet width (B_2/B_1) should be 50% or greater.
3. For Z=3 ft., use L=10 ft. For Z=4 ft., use L=12 ft. For Z=5 ft., use L=15 ft.
   (For Z=0.9 m., use L=3.0 m. For Z=1.2 m., use L=3.6 m. For Z=1.5 m., use L=4.5 m.)

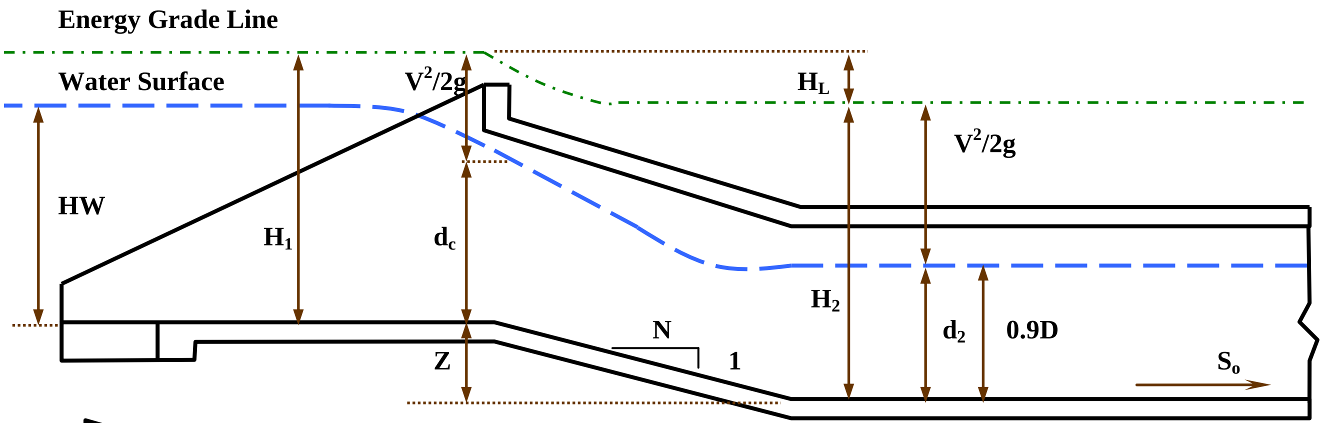
Guidelines for Twin RCBs

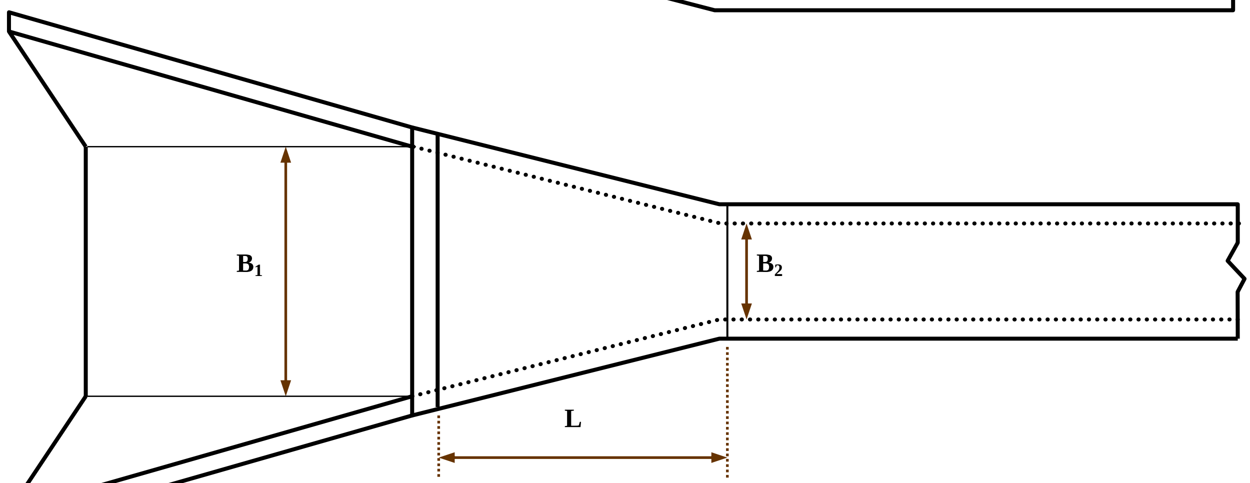
1. Use drop rate (L/Z) of 5:1 (min.)
2. Ratio of barrel width to inlet width (B_2/B_1) should be 60% or greater.
3. L is determined either by (B_1 - B_2) x 4 or Z x 5, whichever is greater. This insures a minimum side taper of 4:1. L should generally be in 5 ft. (1.5 m.) increments.

Definitions

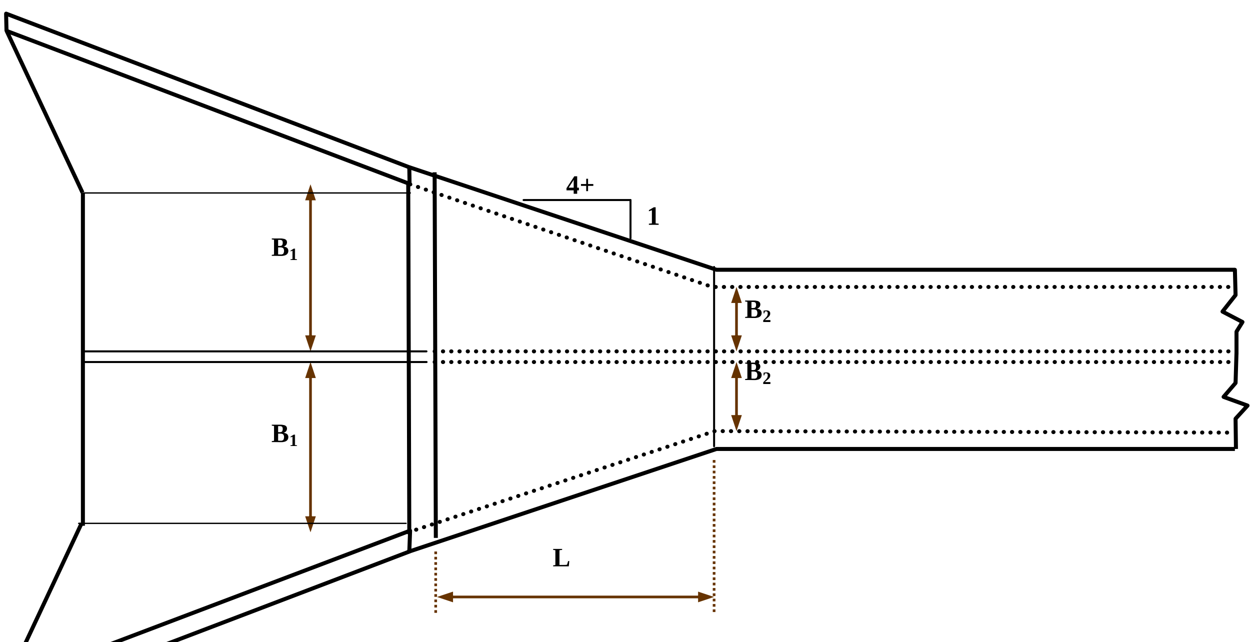
HW -- Headwater from inlet control charts
H_1 -- Specific energy head at inlet
H_2 -- Specific energy head at barrel
B_1 -- Width of inlet opening
B_2 -- Width of barrel opening
D -- Height of opening
H_L -- Energy loss
d_c -- Critical depth
Z -- Drop in flowline required
L -- Length of taper section
S_o -- Slope of barrel
$V^2/2g$ -- Velocity head
N = L/Z = Slope of taper section

Slope Tapered Box Culverts



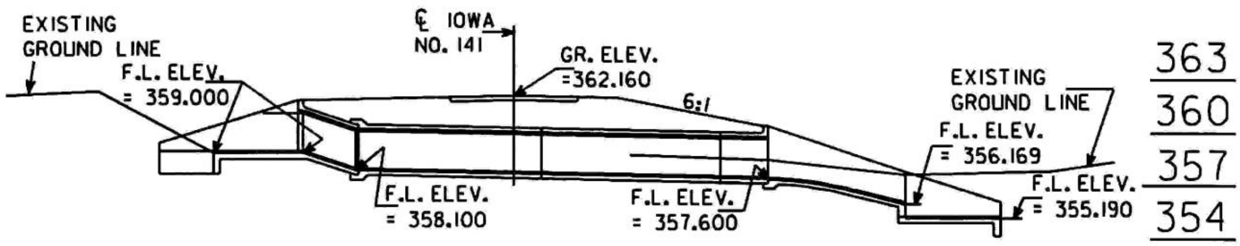


Single RCBs

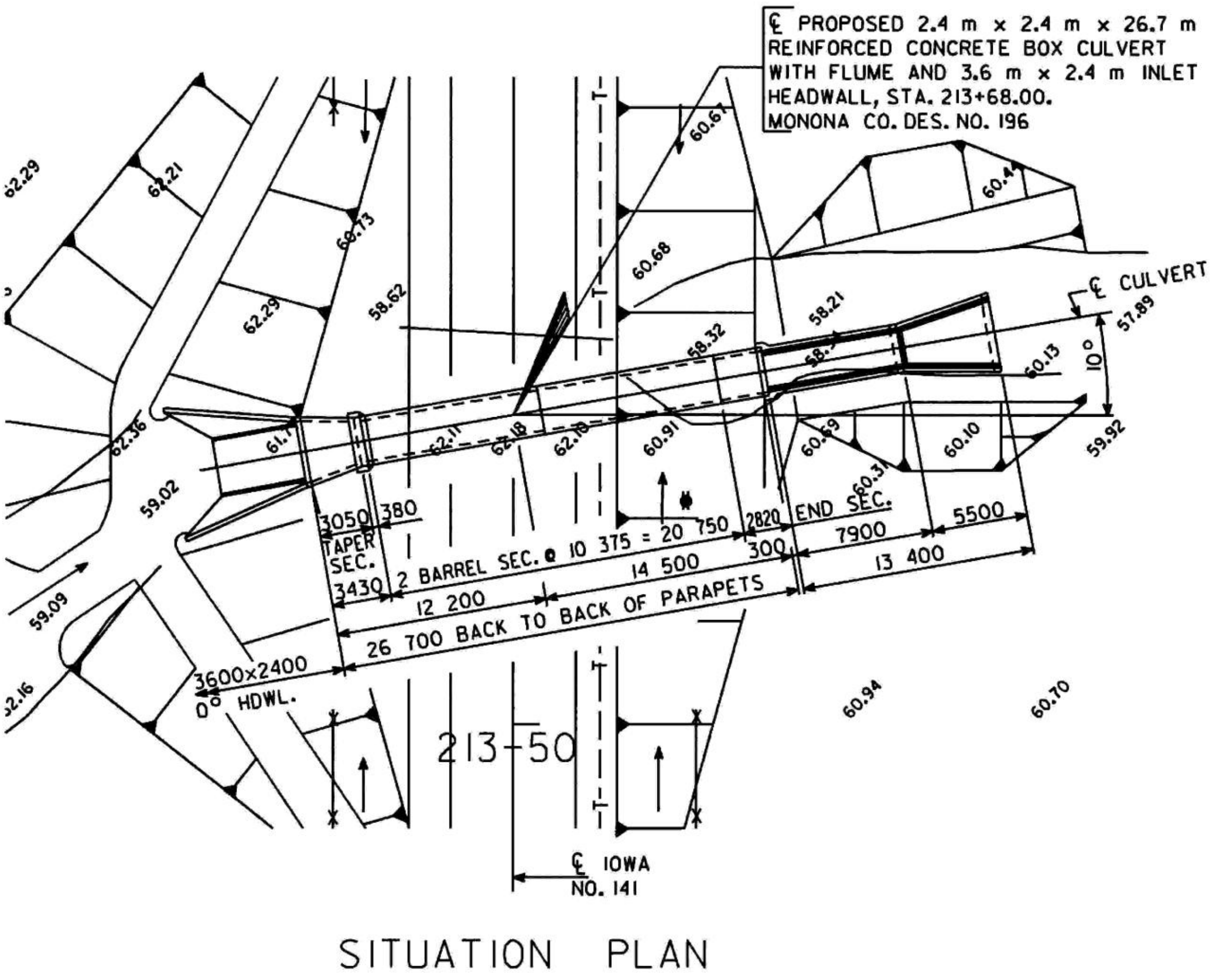


Twin RCBs

Sample Slope Tapered Box Culvert and Flume

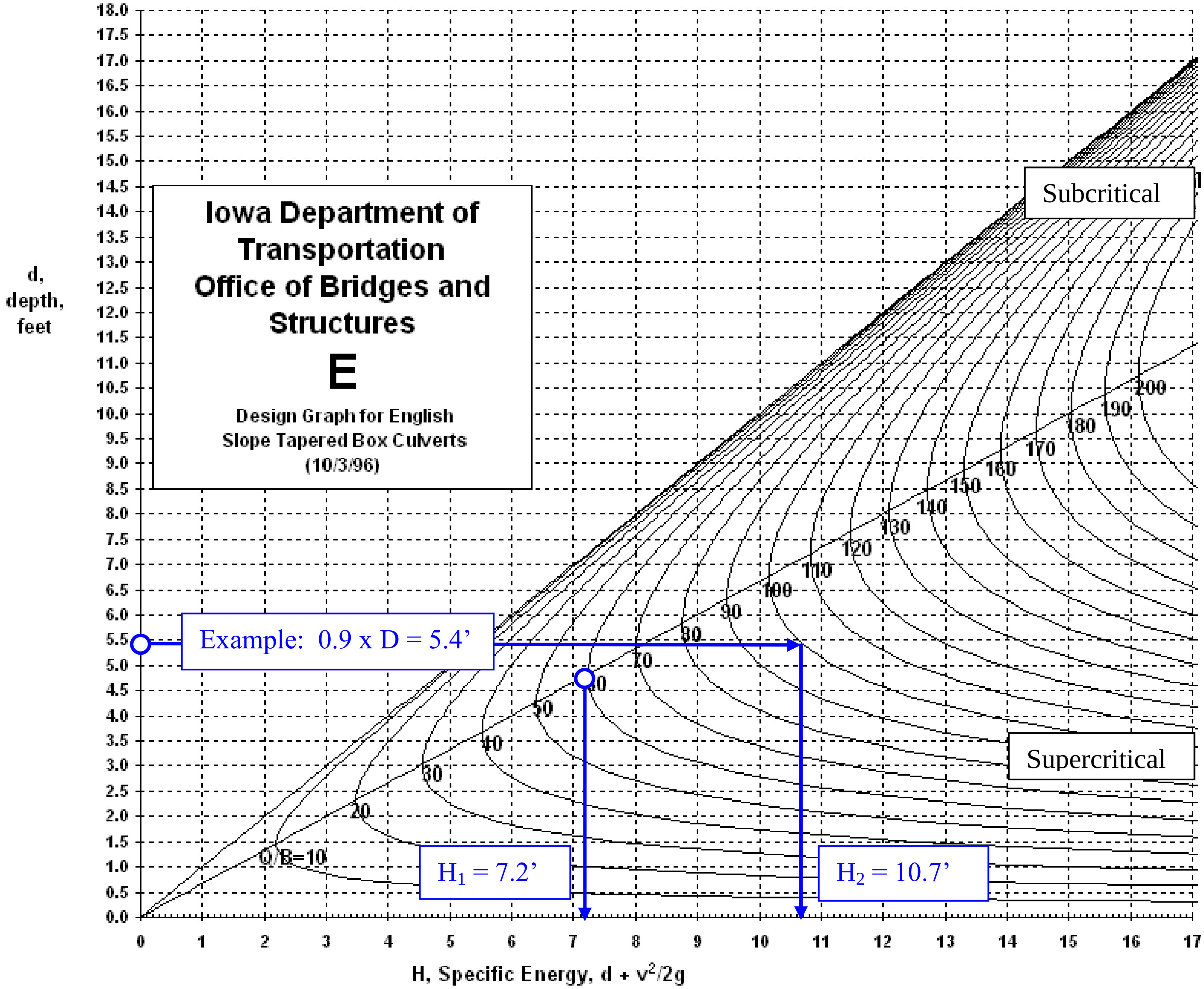


LONGITUDINAL SECTION ALONG ℄ CULVERT

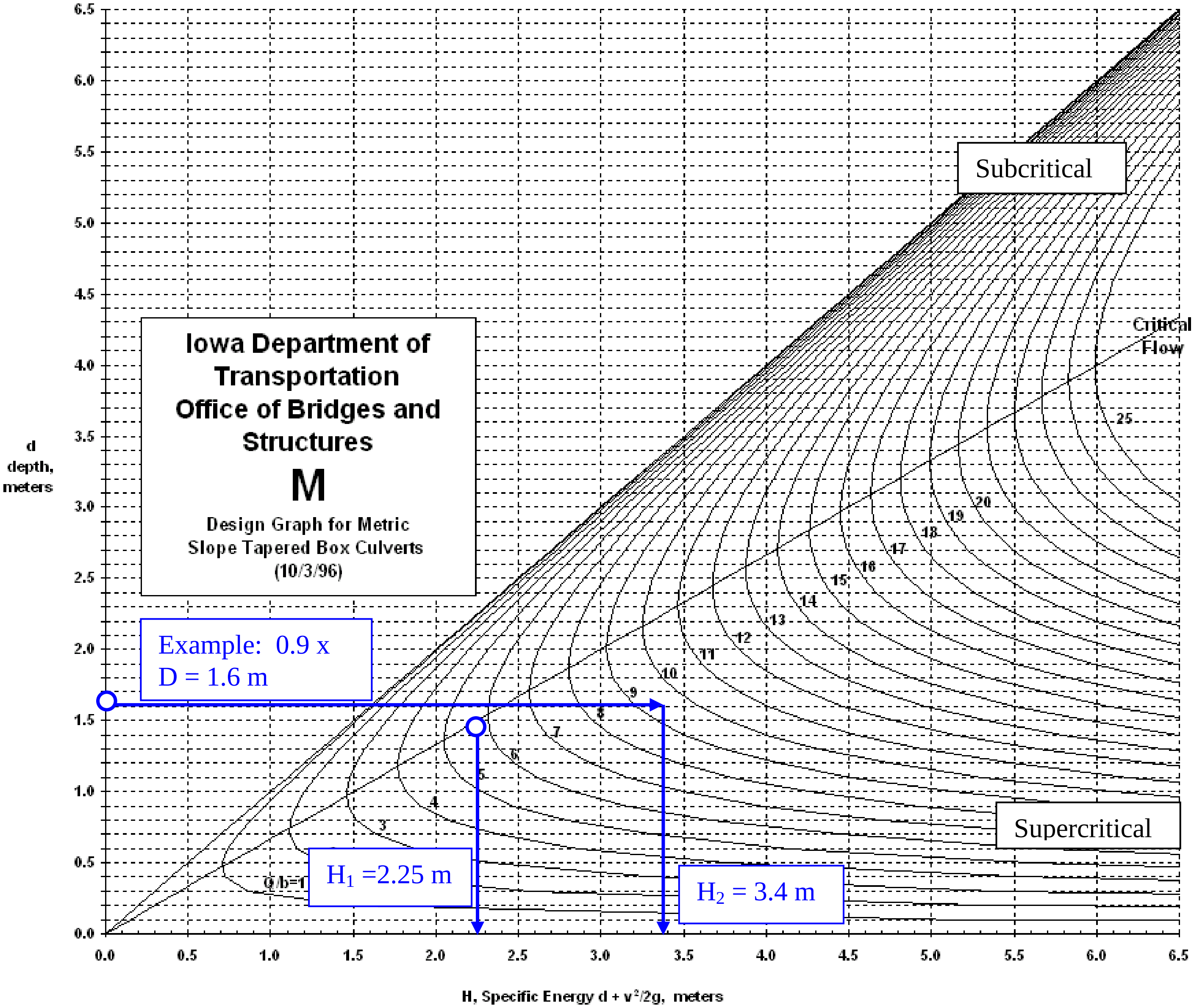


SITUATION PLAN

Design Graph for Slope Tapered Box Culverts (English)



Design Graph for Slope Tapered Box Culverts (Metric)



May 29, 1998

Worksheet for Slope Tapered Box Culverts (English)

Project____________________ County________________ Des. No.________________

Sta.________________ Designer______________ Date_____________________

Variable	**Example**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**
Design Q, ft^3/sec	600				
Inlet Section					
B_1 X D, ft x ft (size of inlet)	10 X 6				
Q/B_1	60				
HW, ft (from HDS #5 nomographs)	7.5				
d_c, ft (from Design Graph)	4.8				
H_1, ft (from Design Graph)	7.2				
Barrel Section					
B_2 X D, ft x ft (size of barrel)	6 X 6				
Q/B_2	100				
0.9 X D, ft	5.4				
H_2, ft (from Design Graph)	10.7				
Slope Tapered Section					
H_L, ft (assumed)	0.2	0.2	0.2	0.2	0.2
Z, ft $(= H_2 - H_1 + H_L)$	3.7				
Selected Z, ft	4.0				
Selected L, ft	12				
Barrel Slope					
$d_n = 0.9$ X D, ft	5.4				
Min. Slope, % (from HDS No. 3 or Mannning=s eqn.)	1.5				
Is the design acceptable?	Yes				

May 29, 1998

Worksheet for Slope Tapered Box Culverts (Metric)

Project______________________ County_________________ Des. No._________________

Sta.________________ Designer______________ Date_____________________

Variable	Example	Trial 1	Trial 2	Trial 3	Trial 4
Design Q, m^3/sec	17.0				
Inlet Section					
B_1 X D, m x m (size of inlet)	3.0 X 1.8				
Q/B_1	5.67				
HW, m (from HDS #5 nomographs)	2.3				
d_c, m (from Design Graph)	1.5				
H_1, m (from Design Graph)	2.25				
Barrel Section					
B_2 X D, m x m (size of barrel)	1.8 X 1.8				
Q/B_2	9.4				
0.9 X D, m	1.6				
H_2, m (from Design Graph)	3.40				
Slope Tapered Section					
H_L, m (assumed)	0.1	0.1	0.1	0.1	0.1
Z, m (= $H_2 - H_1 + H_L$)	1.15				
Selected Z, m	1.2				
Selected L, m	3.6				
Barrel Slope					
d_n = 0.9 X D, ft	1.6				
Min. Slope, % (from HDS No. 3 or Manning=s eqn.)	1.5				
Is the design acceptable?	Yes				

Design Guidelines for
Slope Tapered Pipe Culverts

The purpose of using slope tapered pipe culverts is to reduce construction costs and still provide the same hydraulic capacity and upstream headwater. The concept will be used primarily on Type 1501 culverts which have concrete pipe on a relatively flat slope under the pavement and corrugated metal or polyethylene pipe down the steep foreslope of the highway embankment. The intent is to use available precast concrete pipe appurtenances and thus avoid special, costly designs by the manufacturers. This keeps the cost of material supply, and therefore total installation, lower. For example, by reducing a 48-inch pipe to a 36-inch pie, the cost savings for a 150-foot long culvert may be $25/foot X 150' = $3750. This savings should be compared to the costs of elbows and reducers to decide if a slope tapered inlet is practical at a given site.

The culvert site normally will meet two basic requirements to qualify for a tapered inlet. The first is that the additional costs for special pipe sections are offset by the reduction in construction costs. The second is that the site must have enough fall for the design to perform properly, typically at least four to six feet.

The culvert inlet is made large enough to keep the depth of water at the entrance within allowable limits. The slope taper section Afunnels≅ the water down a steep slope and the barrel diameter decreases. The barrel section is designed to flow nearly full when carrying the design discharge. Frequently the outlet will have a letdown pipe or flume.

Design Steps

There are five basic steps for the hydraulic design a pipe culvert with a slope tapered inlet.

1. Determine the design discharge. The Iowa Runoff Chart shall be used for rural watersheds draining 1000 (400 hectares) acres or less.
2. Determine the allowable depth of water at the inlet. Typically, the Iowa DOT allows one foot (0.3 m) of water above the top of the inlet.
3. Select an inlet size that results in a flow depth less than or equal to the allowable. Inlet control nomographs from FHWA=s AHydraulic Design of Highway Culverts≅ (HDS No. 5) can be used for this.
4. Select a barrel size and slope that results in the barrel flowing less than full. Select a slope steep enough to maintain supercritical flow. Charts in FHWA=s ADesign Charts for Open-Channel Flow≅ (HDS No. 3) have been developed from Manning=s equation and can be used to select the appropriate slope.
5. Determine the drop needed for the slope section. The minimum drop needed is the specific energy at the inlet (H_1) minus the specific energy at the barrel (H_2) plus energy losses (H_L). Specific energy is the depth plus velocity head at a given location. The hydraulic principles for round pipe are the same as described in the section for slope tapered box culverts. Although the appearance of the Design Graph for pipe culverts is different, the calculations are similar.

The following guidelines, chart and worksheet (English units only) are provided to assist in the hydraulic design.

When the inlet will be raised significantly to create a pond, geotechnical concerns must be considered to ensure that seepage through the embankment is not excessive.

Guidelines

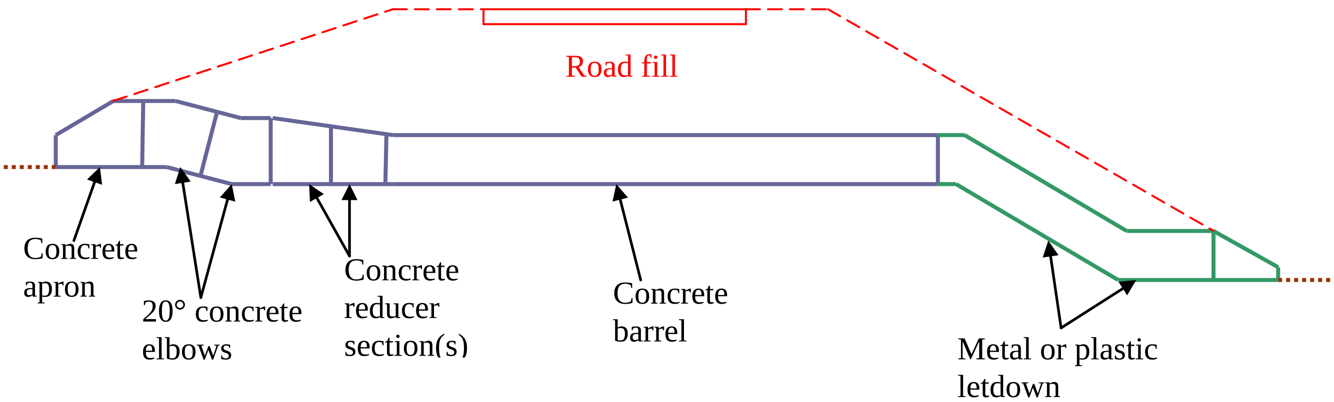
Some of the following guidelines were verified by the hydraulic research in 1997 at FHWA=s Turner-Fairbanks Highway Research Center in Virginia:

1. Use only the reductions in diameter listed in the table. Any variations to this table should be verified with detailed hydraulic calculations.
2. In order to maintain supercritical velocities in the concrete barrel, use the minimum slope or steeper as shown in the table. This assumes a depth of flow of 0.8 x D and an An-value≅ of 0.012. If the discharge, slope or desired depth of flow vary from these assumptions, use FHWA=s ADesign Charts for Open-Channel Flow≅, HDS No. 3, to determine the minimum slope.
3. Concrete pipe reducers are available in four-foot long sections with six inches of diameter reduction per section. For example, if reducing pipe diameter by 12 inches, two reducer sections are needed, resulting in an eight foot length of pipe.
4. For simplicity, design both concrete elbows at 20° each.
5. The 20° elbows end-to-end will give a vertical drop (Z) of approximately 2.1 feet (0.64 meters). If greater drop is needed as determined in the design calculations, a four-foot long section of standard pipe could be installed between the two elbows. This results in a drop of approximately 3.5 feet (1.07 meters).
6. Pipe outlets larger than a 48-inch diameter will generally need a cast-in-place reinforced concrete flume rather than a metal or polyethylene letdown pipe.

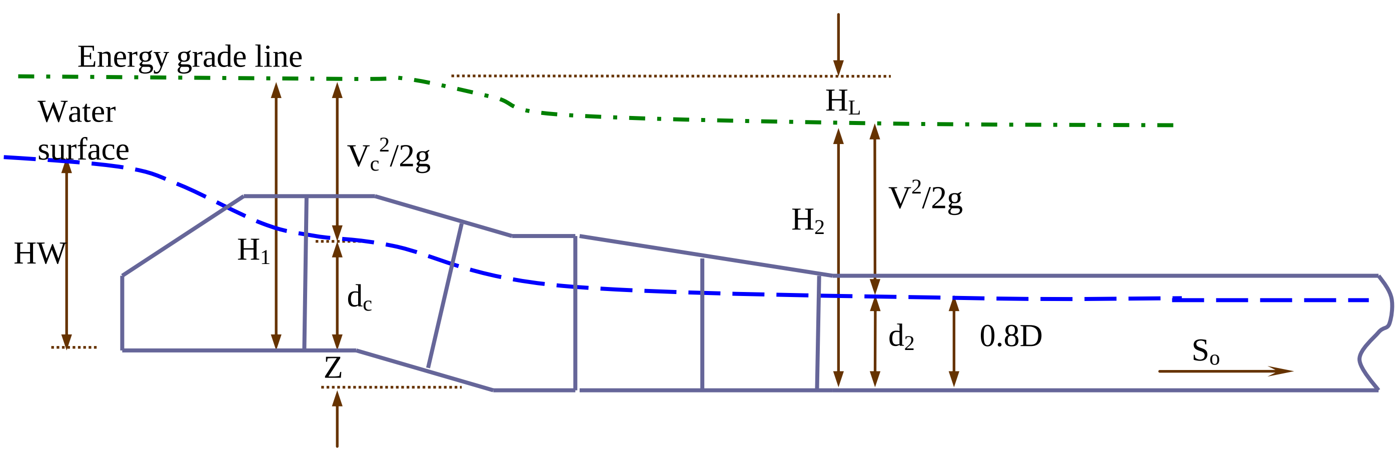
	Diameter Reduction, inches (mm)			
Approx. Q, ft^3/sec (m^3/sec)	**From**	**To**	**Vertical Drop (Z), feet (m)**	**Minimum Barrel Slope, %**
350 (9.9)	84 (2100)	72 (1800)	2.1 (0.64)	0.8
350 (9.9)	84 (2100)	66 (1650)	2.1 (0.64)	1.1
295 (8.4)	78 (1950)	66 (1650)	2.1 (0.64)	1.0
295 (8.4)	78 (1950)	60 (1500)	3.5 (1.07)	1.3
245 (6.9)	72 (1800)	60 (1500)	2.1 (0.64)	1.0
245 (6.9)	72 (1800)	54 (1350)	3.5 (1.07)	1.6
200 (5.7)	66 (1650)	54 (1350)	2.1 (0.64)	1.2
200 (5.7)	66 (1650)	48 (1200)	3.5 (1.07)	2.0
160 (4.5)	60 (1500)	54 (1350)	2.1 (0.64)	0.9
160 (4.5)	60 (1500)	48 (1200)	2.1 (0.64)	1.5
125 (3.5)	54 (1350)	48 (1200)	2.1 (0.64)	1.0
125 (3.5)	54 (1350)	42 (1050)	2.1 (0.64)	1.7
96 (2.7)	48 (1200)	42 (1050)	2.1 (0.64)	1.2
96 (2.7)	48 (1200)	36 (900)	2.1 (0.64)	2.0
71 (2.0)	42 (1050)	36 (900)	2.1 (0.64)	1.3
50 (1.4)	36 (900)	30 (750)	2.1 (0.64)	1.6
33 (0.93)	30 (750)	24 (600)	2.1 (0.64)	2.0

Slope Tapered Pipe Culverts

Modified Type 1501 Letdown

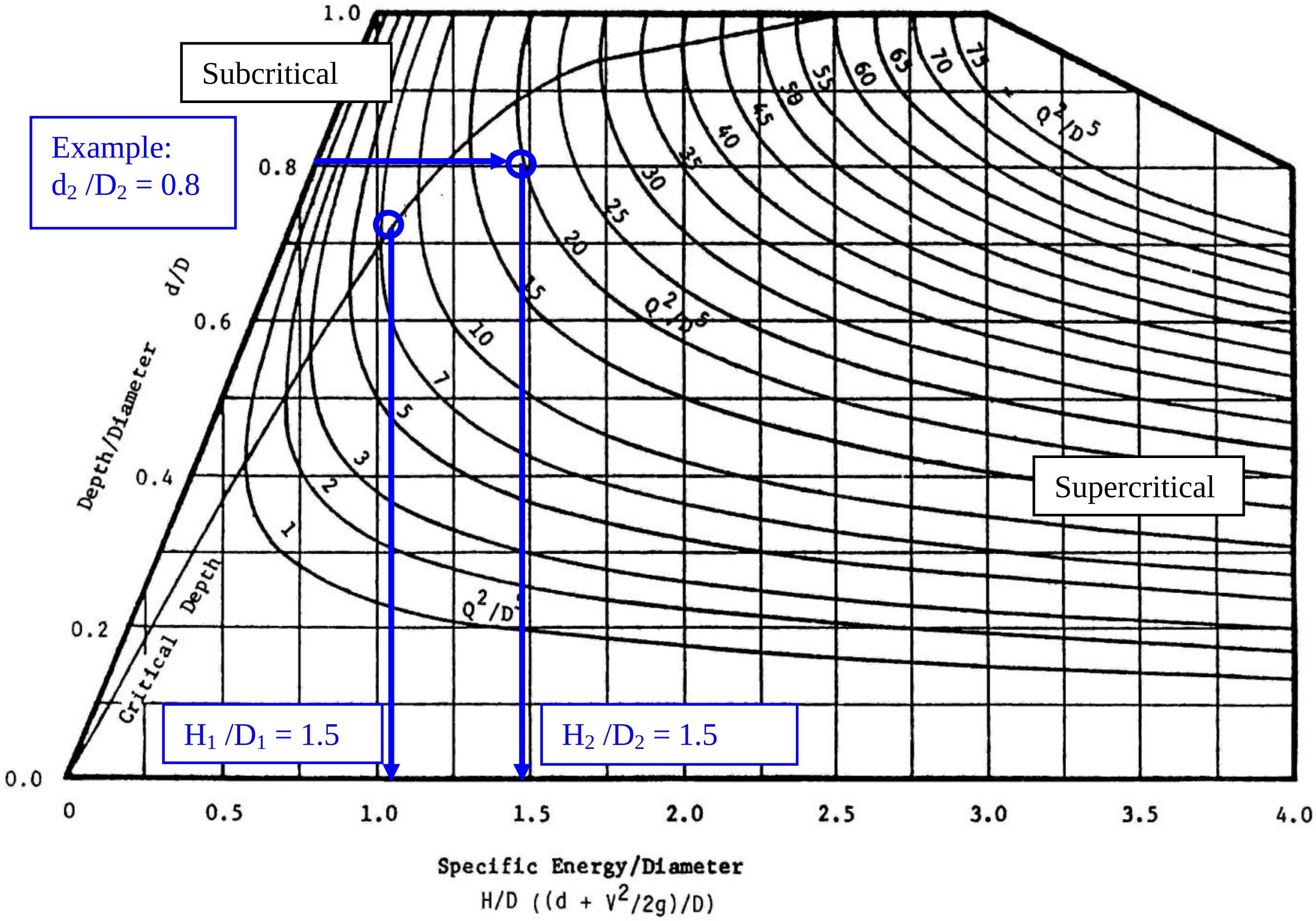


Hydraulic Performance



Design Graph for Slope Tapered Pipe Culverts

Specific Energy Curves for Circular Pipe



May 2, 1997

Worksheet for Slope Tapered Pipe Culverts (English)

Project______________________ County_________________ Sta.________________

Designer___________________ Date_____________________

Variable	Example	Trial 1	Trial 2	Trial 3
Design Q , ft^3/s	250			
Inlet Section				
D_1 , ft (size of inlet)	6.0			
HW, ft (HDS #5)	7.1			
Q_1^2 / D_1^5	8.0			
d_c / D_1 (from Chart)	0.72			
H_1 / D_1 (from Chart)	1.05			
d_c , ft	4.3			
H_1 , ft	6.3			
Barrel Section				
D_2, ft (size of barrel)	5.0			
Q^2 / D_2^5	20.0			
d_n/D_2 = 0.8 (Design max. depth)	0.8	0.8	0.8	0.8
H_2 / D_2 (from chart)	1.50			
H_2 , ft	7.5			
Slope Tapered Section				
H_L, ft (assumed)	0.2	0.2	0.2	0.2
Z, ft (= $H_2 - H_1 + H_L$)	1.4			
Selected Z , ft	2.0			
Barrel Slope				
d_n , ft (= 0.8 X D_2)	4.5			
Min. Barrel Slope, % (table)	1.1			
Is the design acceptable?	Yes			

January 11, 1999

Design Guidelines for Drop Inlet Culverts

Drop inlets for pipe and box culverts can be beneficial solutions to some drainage and erosion problems. Hydraulically, they are useful when a culvert has limited available head upstream. Also, they can be used to raise the flowline to create a pond or stop channel erosion upstream.

When evaluating the hydraulics of drop inlet culverts, two controls must be checked to determine the design high water of the culvert. The first is barrel control using the orifice equation, also known as the full-flow equation, taken from a U.S. Soil Conservation Service technical memorandum for drop inlets. The equation is similar to the outlet control equation in FHWA=s AHydraulic Design of Highway Culverts,≅ HDS No. 5. The second is weir control, using the broad-crested weir equation. The equation giving the highest water elevation is considered the controlling headwater.

A trial and error solution is needed to determine what size of barrel and weir are needed. Start by sizing the barrel and analyzing the hydraulics. When an acceptable size and headwater are obtained, assume a drop inlet opening of 1.5 to 2.0 times the barrel opening. Then calculate the head created by the weir and determine if a different size inlet is needed.

Worksheets (English and metric units) are attached to aid in the calculations.

Barrel (Full Flow) Equation

$$Q = A\left[\frac{2\,g\,H}{1 + K_e + K_b + K_f\ \ L_b}\right]^{0.5}$$

where Q = discharge, ft^3/sec (m^3/sec)
A = area of culvert barrel, ft^2 (m^2)
g = acceleration due to gravity = 32.2 ft/sec^2 (9.81 m/sec^2)
H = head (energy) needed to pass the flow through the barrel, feet (m)
K_e = entrance loss coefficient
K_b = bend loss coefficient
L_b = length of barrel, ft
K_f = friction loss coefficient
= $29.16\ n^2 / R^{1.33}$ (English), or = $19.63n^2 / R^{1.33}$ (metric)
n = roughness coefficient
R = hydraulic radius of barrel = area / wetted perimeter, ft (m)

Assume $K_e + K_b = 1.0$ for typical Iowa DOT drop inlet
n = 0.012 for smooth pipe, or 0.024 for corrugated metal
R = A/2(W + H) for RCBs or D/4 for round pipe barrels
h_o = height of hydraulic grade line at outlet = TW or $(d_c + D)/2$, whichever is greater, ft (m)
(TW can be determined from Manning=s equation using a downstream valley section. d_c can be found in Chart 4 or 14 in FHWA=s HDS No. 5. D is the height of the barrel.)

This results in the following full flow equation, assuming English units and a smooth (e.g., concrete) barrel:

$$Q = A\left[\frac{64.4\ H}{2 + 0.0042\dfrac{L_b}{R^{1.33}}}\right]^{0.5}$$

Or solving for H,

$$H = \left[\frac{0.1246\ \ Q}{A}\right]^2 \left[\ 2\ +\ \frac{0.0042\ \ L_b}{R^{1.33}}\right] \qquad \text{(Equation 1---English)}$$

Equation 1 in metric units converts to the following:

$$H = \left[\frac{0.226\ \ Q}{A}\right]^2 \left[\ 2\ +\ \frac{0.0028\ \ L_b}{R^{1.33}}\right] \qquad \text{(Equation 2---Metric)}$$

H is the head (energy loss) required to pass the flow through the barrel. To determine the headwater (HW) elevation at the inlet, add H and h_o to the outlet flowline elevation, where h_o is either tailwater (TW) depth or $(d_c + D)/2$, whichever is greater. (See Chapter III of FHWA=s AHydraulic Design of Highway Culverts≅, HDS No. 5, for a more detailed discussion of barrel [outlet] control.)

Then compare HW elevation to allowable head water (AHW) elevation. If HW > AHW, a larger barrel is needed. If HW < AHW, either try a smaller barrel size or proceed with the weir control calculations as described below.

Weir Equation

$$Q = C\ L_w\ H^{1.5}$$

where Q = discharge, ft^3/sec (m^3/sec)
C = coefficient. Use C = 3.09 (English units), or = 1.71 (metric units)
L_w = effective length of weir, feet (m). The typical IDOT drop inlet has a parapet on one side, so consider only three sides to determine L_w. (The parapet improves the inlet efficiency by minimizing vortex action.)
H = head, feet (m)

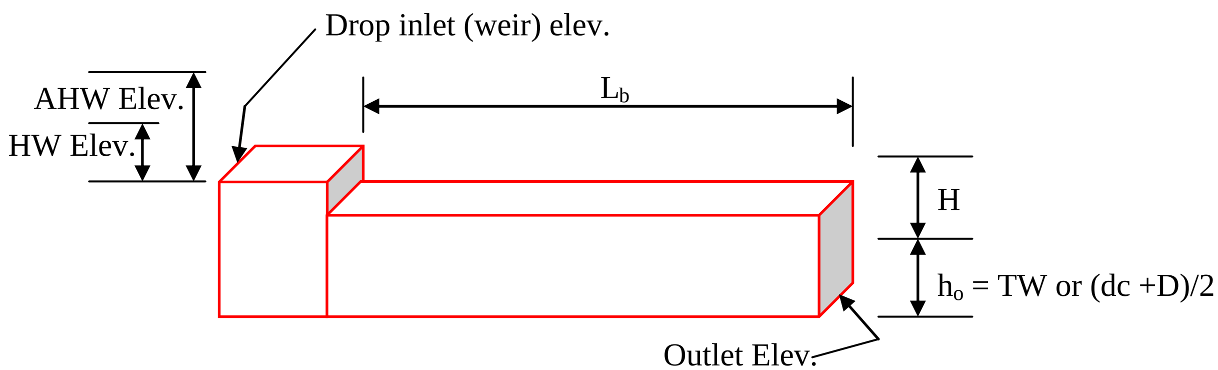
(H actually is depth plus velocity head, but for simplicity assume velocity head as negligible. This will result in a conservative headwater design.)

Or solving for H,

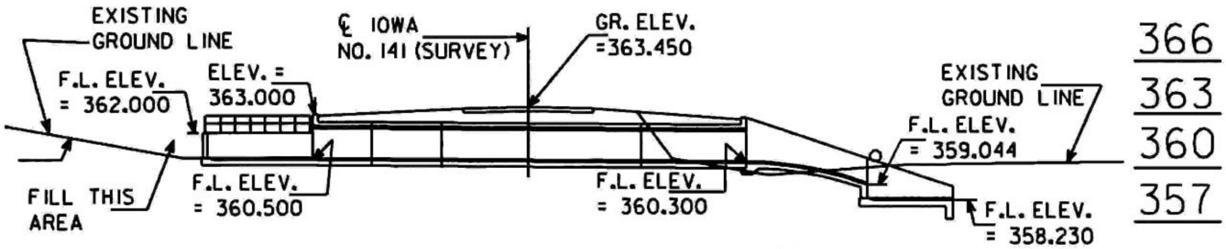
$$H = \left[\frac{Q}{C\ L} \right]^{0.667} \qquad \text{(Equation 3)}$$

H is the head above the drop inlet flowline. To determine HW elevation for weir control, add H to the weir elevation and compare to the AHW elevation. If HW > AHW, then a larger weir is needed. If HW < AHW, either try a smaller weir or proceed with the selected size.

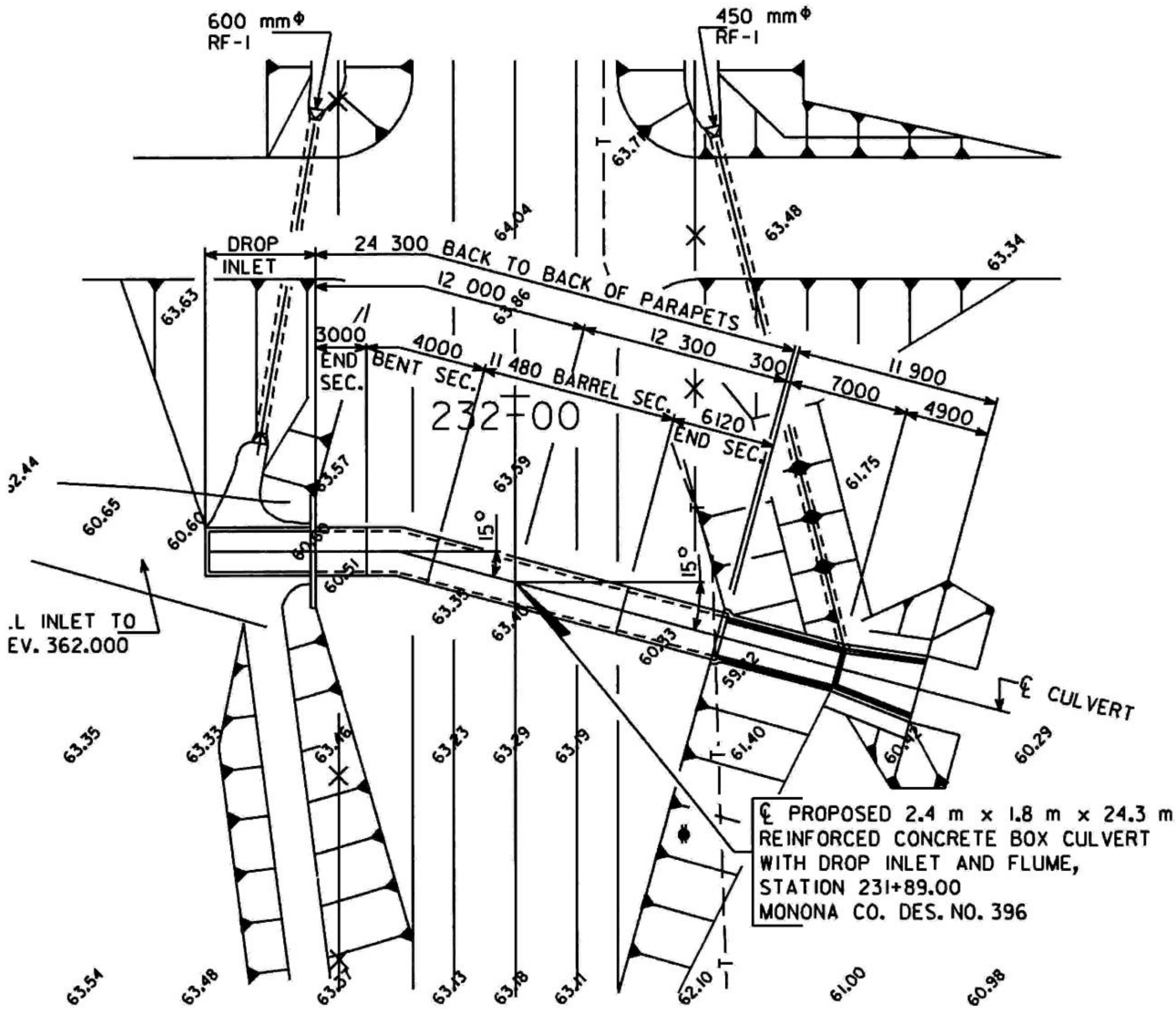
After an acceptable weir size is selected, compare HW for weir control to HW for barrel control. In essence, this comparison finds out which portion of the culvert is the most hydraulically restrictive: the weir or the barrel. The higher HW is the controlling elevation and indicates how high the water will get upstream of the culvert during the design flood.



Sample Drop Inlet Culvert

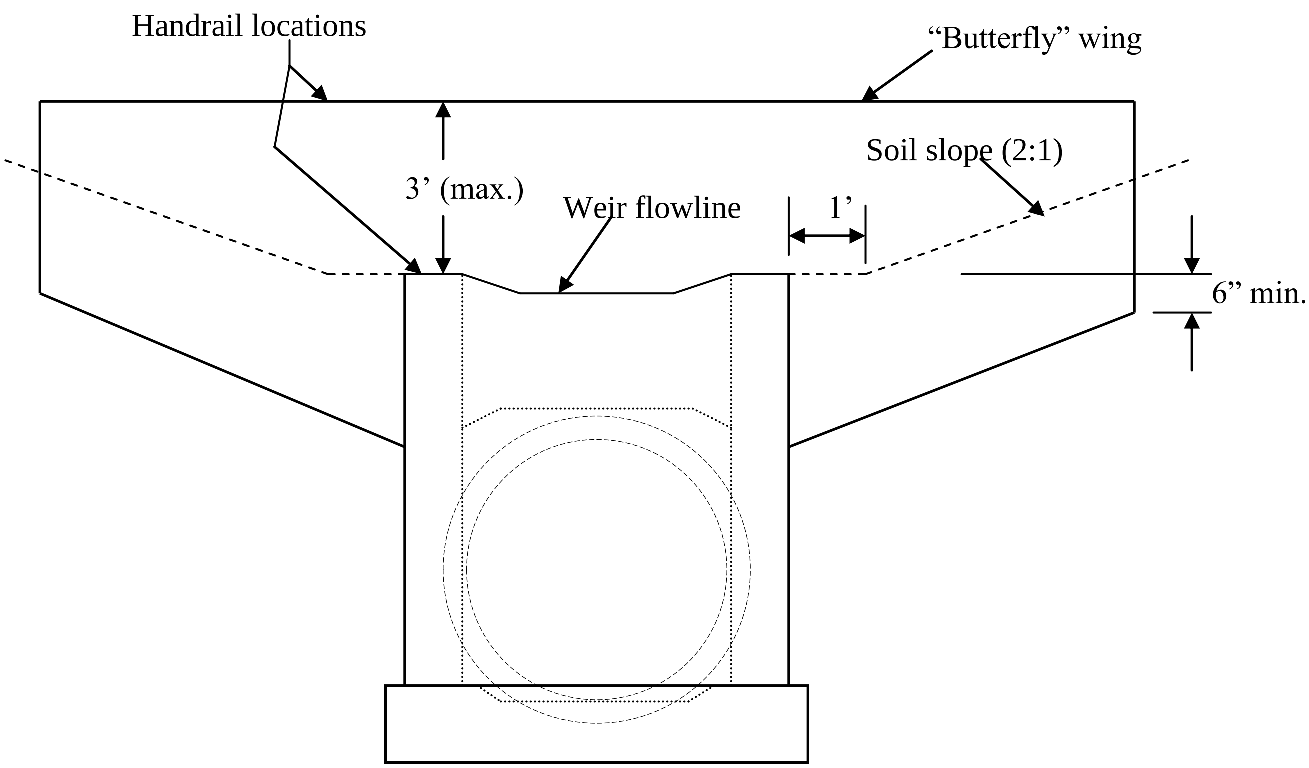


LONGITUDINAL SECTION ALONG ℄ CULVERT

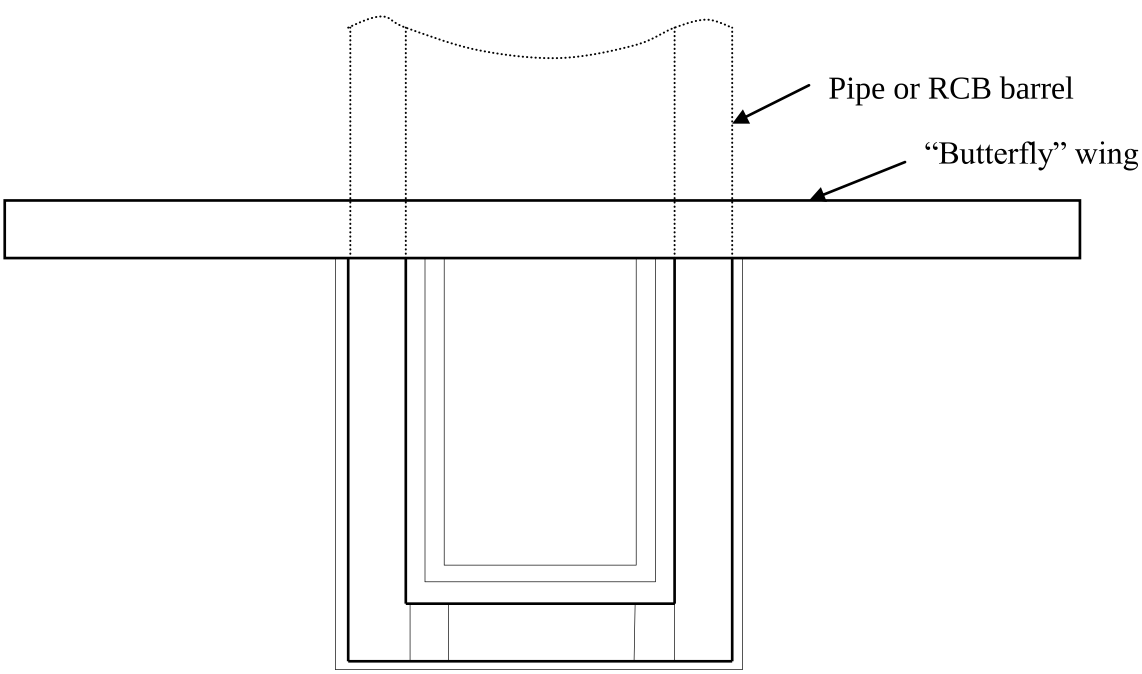


SITUATION PLAN

Typical Drop Inlet Detail



Front view



Plan view

Worksheet for Drop Inlet Culverts (English)

Project______________________ County_________________ Des. No._________________

Sta._______________ Designer______________ Date_____________________

	Example	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**
Design Q, ft^3/sec	150				
Allowable HW Elev. (AHW)	108.0				
Barrel Design					
Barrel Size, ft X ft	4 X 4				
A, ft^2	16				
WP, ft	16				
R, ft (= A/WP)	1.0				
L_b, ft	80				
H, ft (Eqn. 1)	3.2				
$(d_c + D)/2$, feet	3.7				
TW, feet	4.0				
h_o, ft (= greater of TW or $(d_c + D)/2$)	4.0				
Barrel Outlet Elev.	100.0				
HW Elev. (=H + h_o + outlet elev.)	107.2				
Acceptable? If no, try a different barrel size.	Yes. HW < AHW.				
Weir Design					
Weir Size, ft X ft	4 X 8				
C	3.09	3.09	3.09	3.09	3.09
L_w, ft	20				
H, ft (Eqn. 3)	1.8				
Weir Elev.	106.0				
HW Elev.	107.8				
Controlling HW Elev.	107.8				
Acceptable? If no, try a different size.	Yes. HW < AHW.				

Worksheet for Drop Inlet Culverts (Metric)

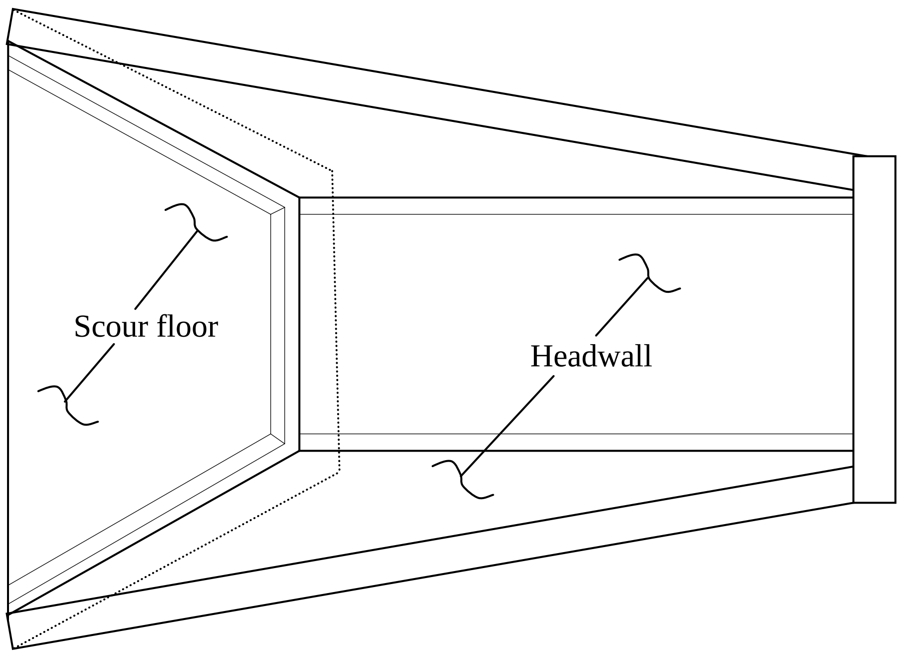
Project_____________________ County________________ Des. No.________________

Sta.______________ Designer_____________ Date____________________

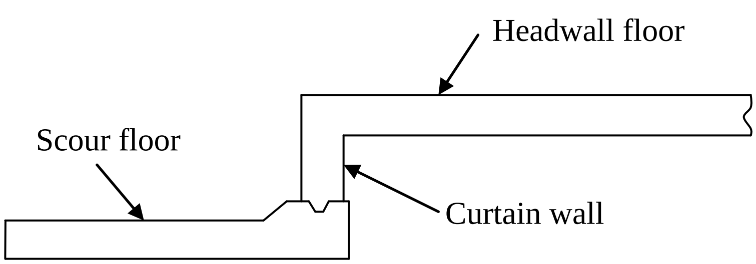
	Example	Trial 1	Trial 2	Trial 3	Trial 4
Design Q, m^3/sec	6.0				
Allowable HW Elev. (AHW)	210.0				
Barrel Design					
Barrel Size, m X m	1.5 X 1.5				
A, m^2	2.25				
WP, m	6.0				
R, m (= A/WP)	0.38				
L_b, m	25				
H, m (Eqn. 2)	0.8				
$(d_c + D)/2$, m	1.3				
TW, m	1.5				
h_o, m (= greater of TW or $(d_c + D)/2$)	1.5				
Barrel Outlet Elev.	207.0				
HW Elev. (=H + h_o + outlet elev.)	209.3				
Acceptable? If no, try a different barrel size.	Yes. HW < AHW.				
Weir Design					
Weir Size, m X m	1.5 X 2.4				
C	1.71	1.71	1.71	1.71	1.71
L_w, m	6.3				
H, m (Eqn. 3)	0.7				
Weir Elev.	208.0				
HW Elev.	208.7				
Controlling HW Elev.	209.3				
Acceptable? If no, try a	Yes.				

	Example	Trial 1	Trial 2	Trial 3	Trial 4
different size.	HW < AHW.				

Typical Scour Floor



Plan view



Section through scour floor

Determining Culvert Lengths

Required Length
The required length of a culvert is generally determined by one of two methods:

1. by the Aclear zone≅; or,
2. by fitting the culvert to the typical cross section, such as the barnroof.

Both methods must be checked and then compared; the **greater** of the two distances is the required culvert length.

The first method uses Table 3.1 from AASHTO=s ARoadside Design Guide≅, which gives a range of minimum clear zone distances which are acceptable for safety. This clear zone is measured from the edge of the driving lane to the back of the RCB parapet or the top opening of the pipe apron. (Note that the clear zone is measured from the edge of the driving lane [typically 3.6 m or 12 ft], not from the edge of any additional pavement that will be used as part of the shoulder.) Only in rare circumstances shall any replacement or extended culvert be shorter than required by Table 3.1. (One exception is the inlet end of a median drain with an apron guard.)

The second method computes the culvert length by Afitting≅ the culvert to the roadway barnroof section. In other words, the computed length is determined by intersecting the barnroof with the back of the RCB parapet or the top opening of the pipe apron. See ADetermining Culvert Lengths Using the Computations Section on Pink Sheets≅ in this appendix for this method. This is the primary purpose of the Computations Section on the pink sheets.

To repeat the statement above, the **greater** of the two distances from these methods is the required culvert length.

Computations Section on Pink Sheet
The AComputations≅ section on the pink sheet should be used to determine the lengths of pipe and box culverts. The terms from the pink sheet are defined below to aid in the calculation of lengths based on the typical cross section (e.g., Abarnroof≅ section) for a given project. The calculated length must be compared to the minimum length required by clear zone criteria. The greater of the two lengths will govern. See comments on line 12.

1. **Profile Grade -** Grade at a pre-determined station. Taken from the Road Plan and Profile sheet. If the structure is skewed, the Grade Rt and Lt could vary. Use the grade at the station where the parapet or top of pipe opening is perpendicular to road centerline.

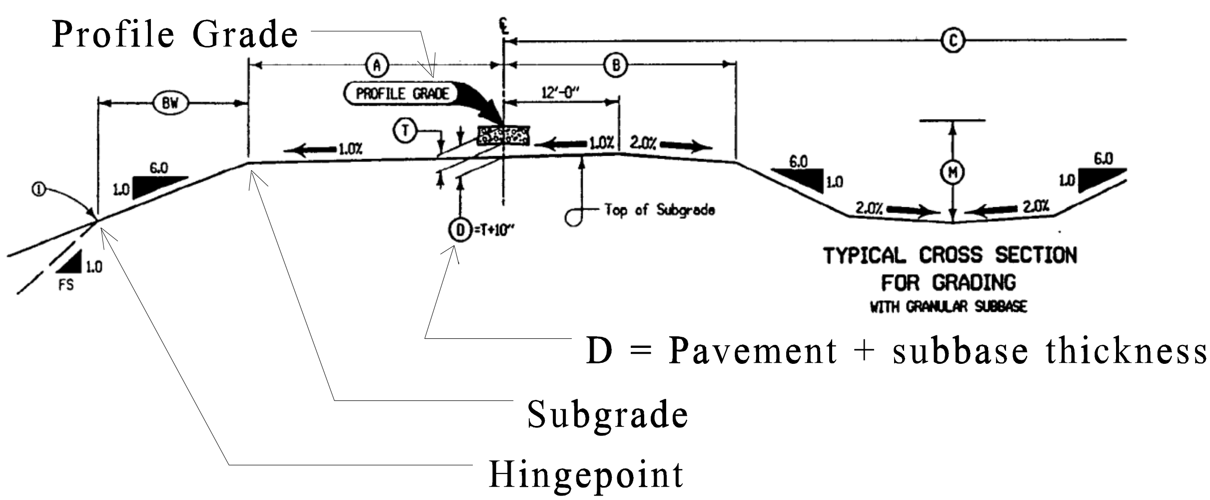
2. **Vertical Drop (Subgrade or Hinge Point) -** Vertical distance down from Profile Grade to Subgrade Point to Hinge Point. For any given project, the Vertical Drop generally stays constant except in areas with superelevations. See the following drawing that depicts the Vertical Drop and the Working Point Elevation.

3. **Working Point Elevation -** Line 1 minus Line 2.
Either the subgrade elevation or the hingepoint elevation is used as the AWorking Point Elevation≅. See the typical grading section below. Which point to use in the computation of culvert length depends on the elevation of the top of the culvert. If the top of the pipe opening

(or RCB parapet) is above the hingepoint elevation, then the subgrade is used as the working point. If the top of the pipe opening (or RCB parapet) is below the hingepoint elevation, then the hingepoint is used as the working point.

<u>Subgrade Elevation</u>
Profile grade elevation
-Pavement and subbase thickness
-Subgrade cross slope times distance (typically 1% X >A=)
= Subgrade elevation

<u>Hingepoint Elevation</u>
Subgrade elevation
->BW=) 6:1 slope
= Hingepoint elevation



4. **Flowline -** This is the actual proposed culvert flowline elevation, not the ground elevation.

5. **Difference** - Line 3 minus line 4 = vertical difference between the Working Point Elevation and the culvert Flowline Elevation.

6. **(D+T) or (H+Hdwl)**
   D + T (for pipes only) = Diameter of pipe + the thickness of pipe (see RF-1).

   H + HDWL (for RCBs only) = Nominal height of the box (e.g., 2400 mm) + the height of parapet (600 mm) and frost trough (100mm).

7. **Difference - ** Height Difference (line 5) minus D+T or H+HDWL (line 6). Gives the actual vertical distance between the top of structure to soil at the working point (hinge point or subgrade).

8. **Slope -** Embankment Slope from the working point (subgrade or hinge point) to the top of pipe opening or parapet. The slope is generally 6:1 when using the subgrade as the working point or 3:1 when using the hingepoint.

9. **Working Point (Subgrade or Hinge Point) to End of Foreslope** - Line 7 multiplied by line 8 = the horizontal distance from the working point to the top of the pipe opening (or the RCB parapet).10. **Distance = Centerline to Working Point -** On 2-lane roadways, this is the horizontal distance from the centerline of roadway to the working point (Subgrade or Hingepoint).

   On 4-lane roadways, this is the horizontal distance from the construction centerline (typically the median) to the working point (Subgrade or Hingepoint).

11. **(1.5:1) or (Dimen. >B=) for pipes only -** Line 9 determines the culvert length only to the top of the pipe, so the distance from the top of the pipe to the end of the apron must be accounted for. For 1200mm or smaller pipes, use the >B= dimension of the pipe (see Road Standards); for 1350mm or greater pipes, use 1.5 x D. For box culverts, Line 11 is zero.

12. **Length -** This is the total calculated length of the culvert from the roadway centerline to either the end of the pipe or the back of RCB parapet. This is the sum of lines 9, 10 and 11. Then compare this calculated length to the minimum length to be sure it meets the minimum clear distance as follows:

    For RCBs, minimum length = Lane width + Clear zone
    For pipes, minimum length = Lane width + Clear zone + Apron >B= dimension

   Select the greater of calculated length or minimum length.

13. **Secant of Skew Angle -** If structure is skewed, list the secant of the angle the structure is to centerline of roadway.

14. **Length on Skew -** Line 12 times line 13 gives the actual length along the centerline of the culvert.

15. **Add for Hdwl Skew -** The length (line 12 or 14) of the structure is calculated along the centerline of the culvert. However, if the parapet of the headwall is not parallel to the roadway (e.g., a 0E skewed headwall with a 10E skewed barrel), then one corner of the headwall will fall closer to the roadway than the centerline of the culvert. This corner must be extended to equal the length that was calculated on the centerline (line 12 or 14). This situation will also pertain to all pipes; a length must be added to get the end of the apron beyond this point.

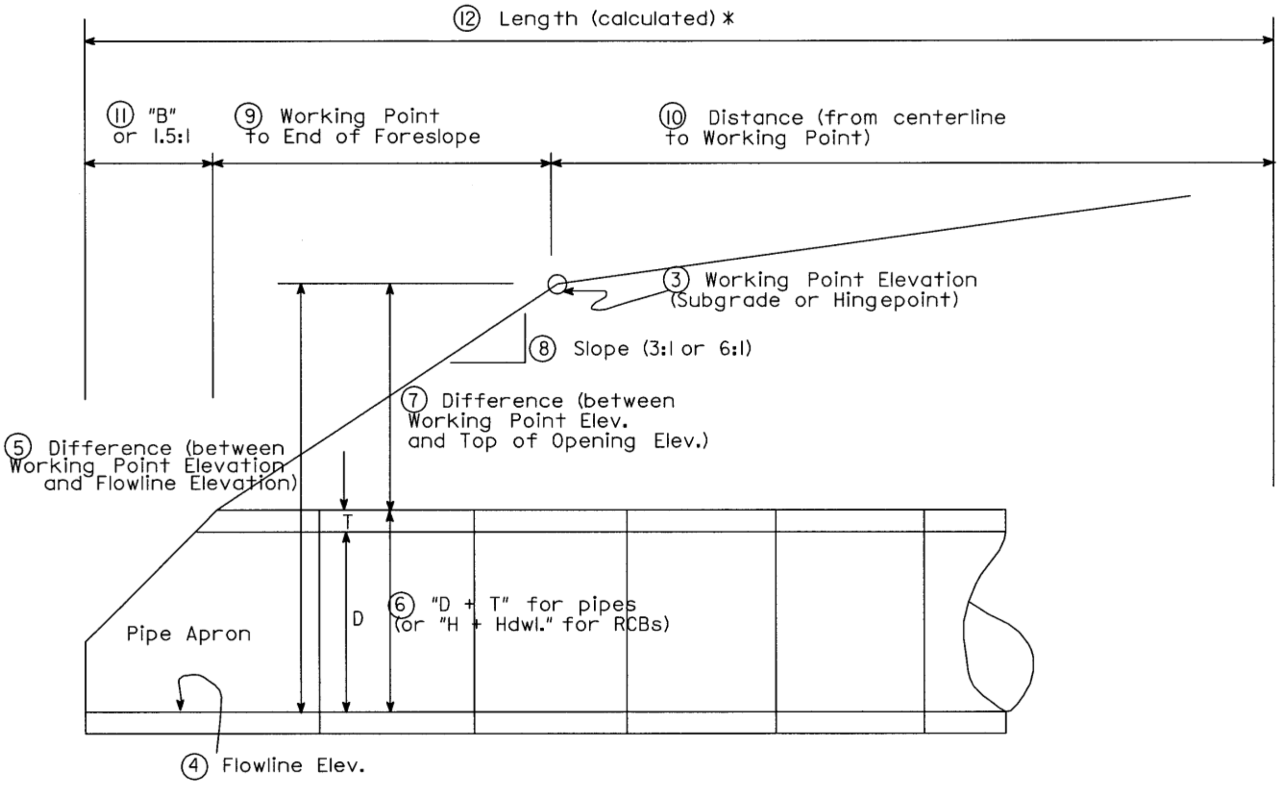
16. **Length -** Add ALength on Skew≅ (line 14) and AAdd for Hdwl Skew≅ (line 15).

17. **Length Present Structure -** If designing an extension, determine the length of the existing structure from the road centerline to the front (not the back) of the RCB parapet

or to the first pipe barrel section.

18. **Extension -** Length (line 16) minus Length Present Structure (line 17). This gives the extension length needed.

Pink Sheet----Computations Section



* Compare calculated length to the "clear zone" minimum length. Use the greater length.

Sample Pink Sheet

Form 621001
3-93

Iowa Department of Transportation
Highway Division
Bridge Survey Record
FIELD NOTES FOR CULVERTS

Township 72N Range 11W Section 25 Civil Township Locust Grove

Station Present Structure or Stream — Station Proposed Culvert 344 + 70

Drainage Area in Acres 6 El. Hi. Water — Character Water Shed R

Upstream Land Use Cult. Anticipate Any Change? No

Bench Mark No. —

Type and Elev. of Low Upstream Buildings —

Present Structure: Type None Design No. ____ Br. Rdwy. ____

Spans ____ Ht. ____ Length: B. to B. Ppts. ____ Pipe ____ Flume ____

Elevation: Grade ____ Inlet ____ Outlet ____ Flume Outlet ____

Condition ____ Skew Angle ____

Proposed Culvert: Type 1501, RF-1 & CMP Fin. Rdwy. Width (Sh-Sh) 40′

Spans 24″ Ht. — Length New Constr: ~~RCB~~ CMP 82′ ~~Pipe~~ RF-1 60′ + 1-RF-3 Aprons ~~Flume~~ 1-RF-5

Elevation: Profile Grade 731.20 F.L. Lt. 701.0 F.L. Rt. 725.4 F.L. Other 721.5, 702.1

Ext. Lt. — Rt. — Total Length Lt. 126′ Rt. 46′ Skew Angle 0 ~~(Lt.) (Rt.)~~ Ahead

— Contr. Dike — Sta. — El. — Type — Road Contr. Ditch outlet

Design Q 18 C.F.S. Frequency 50 Yr. Design High Water Elev. 728.1 Depth 2.7 Ft.

Design Fill Height 5 Ft. Pipe Class 2000 D. Class Bedding C — ADT = — VPD

Disposition of Present Structure —

Remarks A = 76′, B = 60′, C = 2′, E = 20′, Q = 6.5′
Two – 16° CMP elbows, One RF-2 Type C-3 adapter

Computations

	Left		Right	
1	Profile Grade Elev.	731.20	Profile Grade Elev.	731.20
2	Vert. Drop {Subgrade or / Hinge Point}	- 4.7	Vert. Drop {Subgrade or / Hinge Point}	- 1.9
3	Working Point Elev.	= 726.50	Working Point Elev.	= 729.3
4	Flow Line	- 701.0	Flow Line	- 725.4
5	Difference	= 25.50	Difference	= 3.9
6	(D + "T") or (H + Hdwl.)	- 2.3	(D + "T") or (H + Hdwl.)	- 2.3
7	Difference	= 23.2	Difference	= 1.6
8	Slope (6:1, 3:1 etc.)	× 3	Slope (6:1, 3:1, etc.)	× 6
9	Working Point to End of Foreslope	69.6	Working Point to End of Foreslope	9.6
10	Dist. = ℄ to Working Point	+ 48.0	Dist. = ℄ to Working Point	+ 28.0
11	(1½:1) or Dimen. "B" 12 + 30 + 3.6	+ 3.6	(1½:1) or Dimen. "B" 12 + 30 + 3.6 =	+ 3.6
12	Length, Calc. or Min (45.6)	121.2	Length, Calc. or Min (45.6)	~~41.2~~ 45.6 Min.
13	Secant of Skew Angle	×	Secant of Skew Angle	×
14	Length on skew		Length on skew	
15	Add for hdwl. skew	+	Add for hdwl. skew	+
16	Length		Length	
17	Length pres. struct.	-	Length pres. struct.	-
18	Extension		Extension	

Sample Pink Sheet

Form 621001
3-93

Iowa Department of Transportation
Highway Division
Bridge Survey Record
FIELD NOTES FOR CULVERTS

Ramp "D"

Township 72N Range 11W Section 29 Civil Township Locust Grove

Station Present Structure or Stream — Station Proposed Culvert 4527 + 56.00

Drainage Area in Acres 14 El. Hi. Water — Character Water Shed F

Upstream Land Use Cultivated Anticipate Any Change? No

Bench Mark No. —

Type and Elev. of Low Upstream Buildings —

Present Structure: Type None Design No. ___ Br. Rdwy. ___

Spans ___ Ht. ___ Length: B. to B. Ppts. ___ Pipe ___ Flume ___

Elevation: Grade ___ Inlet ___ Outlet ___ Flume Outlet ___

Condition ___ Skew Angle ___

Proposed Culvert: Type 1201 RF-1 Fin. Rdwy. Width (Sh-Sh) 26'

Spans 24"Ø Ht. — Length New Constr: RCB — Pipe 94' + 2 Aprons Flume —

Elevation: Profile Grade 756.45 F.L. Lt. 748.4 F.L. Rt. 740.8 F.L. Other 741.1

Ext. Lt. — Rt. — Total Length Lt. 50' Rt. 56' Skew Angle 20° ~~Lt.~~ Rt. Ahead

Road Contr. Dike Lt. Sta. 4527+70 El. 751.3 Type M ___ Contr. Ditch ___

Design Q 23 C.F.S. Frequency 50 Yr. Design High Water Elev. 751.8 Depth 3.4 Ft.

Design Fill Height 7 Ft. Pipe Class 2000 D. Class Bedding C — ADT = — VPD

Disposition of Present Structure —

Remarks F = 30' , 5° bend (RF-13)

Computations

	Left		**Right**	
1	Profile Grade Elev. 4527+40	756.64	Profile Grade Elev. 4527+65	756.31
2	Vert. Drop {Subgrade or Hinge Point	- 5.0	Vert. Drop {Subgrade or Hinge Point	- 5.0
3	Working Point Elev.	= 751.64	Working Point Elev.	= 751.31
4	Flow Line	- 748.4	Flow Line	- 740.8
5	Difference	= 3.24	Difference	= 10.51
6	(D + "T") or (H + Hdwl.)	- 2.3	(D + "T") or (H + Hdwl.)	- 2.3
7	Difference	= 0.94	Difference	= 8.21
8	Slope (6:1, 3:1, etc.)	× 3	Slope (6:1, 3:1, etc.)	× 3
9	Working Point to End of Foreslope	2.8	Working Point to End of Foreslope	24.6
10	Dist. = ℄ to Working Point	+ 40.0	Dist. = ℄ to Working Point	+ 24.0
11	(1½:1) or (Dimen. "B")	+ 3.6	(1½:1) or (Dimen. "B")	+ 3.6
12	Length, Calc. or Min (16+20+3.6= 39.6')	46.4	Length, Calc. or Min (20+3.6 23.6')	52.2
13	Secant of Skew Angle 20°	× 1.06	Secant of Skew Angle 20°	× 1.06
14	Length on skew	49.4	Length on skew	55.3
15	Add for hdwl. skew	+ —	Add for hdwl. skew	+ —
16	Length Use →	50'	Length Use →	56'
17	Length pres. struct.	- —	Length pres. struct.	- —
18	Extension	—	Extension	—

Guidelines for Using the 1000-Series Drainage Structure Typicals in Road Design Details Manual (Green Book)

The following remarks should be considered when designing pipe culverts. Pay careful attention to the graphics and notes listed in the 1000-Series of the Green Book. A common mistake made when designing culverts is not listing all dimensions in the Remarks space on pink sheets. Also, needed items such as the angle of bends or RF-14 connected pipe joints are often forgotten and not placed in Remarks. These items plus many others on the pink sheet are necessary to properly complete the culvert tabulations in the road plans. Discussion is also provided for Typicals 4304 and 4311 for foreslope shaping at culverts.

Type 1101
This is used primarily for concrete pipes under pavements. See 1601 for Unclassified pipes under unpaved sideroads and entrances.
Note that "Lt." and "Rt." are to end of apron. "Length" of pipe section is Lt. + Rt. minus apron lengths.
May be used without aprons (e.g., temporary pipes).
Must specify material such as concrete, CMP, or PEP.
If RF-1 (concrete) is used, RF-14 type 3 connected pipe joints must be specified in Remarks.
If RF-1, use 100D as a minimum under paved roads.

Type 1102
Teed pipes are generally not recommended except in a side ditch outside the clear zone.
Same comments as for type 1101.
Specify G_1 dimension and indicate size of tee. See RF-21 for description of tee. Must note tee in the Remarks space of pink sheet. Also, tabulate G_1 in Remarks space.
Type 1504 is similar except it has a half-round flume.
See also type 1202.

Type 1201
Normally used with concrete pipe. See type 1401 for a similar culvert as a sideditch letdown and type 1602 for an unpaved road.
May be used as a cross road pipe if the slope of an 1101 would be steeper than approximately 5%. If the fall across the roadway is greater than approximately 2.4 m, or if the fill above the bend is greater than approximately 3.0 m, consider using type 1501 for ease of construction.
Gradient of pipe beyond bend should be less than 1%.
Needs RF-14 connected pipe joints (type 3).
Specify length "F" and desired bend type and bend angle in Remarks space.
See "special note" on standard RF-13, especially on large pipe.
For bends greater than 10E, consider using elbows.

Type 1202
Generally used in conjunction with types 1102 or 1504.

To be used as the inlet to a crossroad pipe when all the flow is coming down a steep sideditch (slope greater than approximately 4%). This inlet will prevent the sideditch water from bypassing the inlet and overtopping the adjacent ditch block and will allow the sideditch water to "turn the corner" within the pipe.
Tabulate pipe cap, if needed (RF-21) in Remarks.

Type 1301
Commonly used to extend existing structures.
Length Rt. & Lt. is measured to end of apron.
Length of pipe = A + B, **not** Lt. + Rt.
Tabulate A and B in Remarks space.
When extending a pipe with a pipe, if the slope of extension is different from the slope of existing pipe, RF-2 type C-1 connection will be required. Tabulate RF-2 connection in Remarks space.

Type 1302
Commonly used to extend existing structures.
Skew angle of extension is different than skew of pipe. The extension skew is referenced to the existing pipe, not the centerline of road, e.g., skew is 15E Rt., not 15E Rt. ahead. Note on the pink whether skew is the pipe skew or the extension skew.
If the extensions on both ends of an existing structure are skewed, note in Remarks how much each extension is skewed, e.g., "Right end or outlet is 15E Rt., Left end or inlet is 20E Rt."
May need RF-2 type C-1 connection if the slope of the pipe extension is different the existing pipe.
Need to tabulate RF-14 pipe joint connections for RF-1 extensions.
Use an elbow if the bend is more than 10E. Tabulate bend in Remarks.

Type 1303, 1304
These Typicals may be used for extensions if the slope of a straight extension would be greater than approximately 5%.
Tabulate A, B, C, D, and E and degree of elbow in Remarks.
The flowline of the elbow should be at or slightly above natural ground elevation.
The flowline of half-round pipes should be approximately 1.0 to 1.5 m below natural ground at its terminus. This allows a natural scour hole to develop.
See type 1302 for skew note.
RF-14 type 3 pipe connectors must be noted in Remarks.
The diameter of a half-round is limited to 1050 mm.
Maximum "B" = 7.3 m. Lengths greater than this tend to settle, resulting in separated joints.
Using Type 1305 is often a good alternative to 1303 and 1304.

Type 1305
Commonly used for extensions.
Designer must select either CMP or PEP for the outlet portion of the pipe.
Tabulate A, B, C, D, E, elbows, and RF-2 adapter in Remarks.
Minimum "C" = 0.6 m

The connection between the concrete and corrugated pipes should extend beyond proposed shoulder line. The flowline at this point should be approximately 2 m below shoulder elevation.
Specify elbows to nearest degree.
Length "B" portion should be approximately parallel to foreslope.
The minimum earth cover is shown as 600 mm. The desirable cover is equal to the diameter of the pipe, e.g., a 1050 mm pipe should have approximately 1050 mm of cover. This helps resist uplift forces.
Outlet aprons are not always necessary if the outlet draw is steep. Aprons may separate from the pipe if a scour hole develops.

Type 1401 & 1403
Should be used for a side ditch letdown. See types 1201, 1501 and 1503 for paved roadways and type 1602 for unpaved roadways.
Note that the Location point is at the inlet of the pipe, not at the centerline of dike or roadway.
Dike (see standard RL-4) over letdown should be Type F, with a 6 m top width for structures 1200 mm and larger.
Maximum size is 1500 mm to prevent uplift of the CMP inlet. For larger culverts consider using concrete pipe or box culverts.
Outlet aprons are optional if outlet is next to RCB.
Tabulate elbows, diaphragms, A, B, & C in Remarks.
Dimension elbows to the nearest degree.
Length "B" portion should be approximately parallel to the fill slope over pipe on type 1403.
Minimum cover over length "C" is 300 mm. The minimum earth cover over length "B" is shown as 600 mm. The desirable cover over "B" is equal to the diameter of the pipe, e.g., a 1050 mm pipe should have approximately 1050 mm of cover. This helps resist uplift forces.

Type 1407
May be used when inlet elevation must be lowered due to limited available earth cover.
Maximum height of the wall is dimension "A" on the RF-3 standard for aprons.
Tabulate in the Remarks space the number and size of planks required.

Type 1501 and 1503
See comments for 1305
For type 1501, designer must select either CMP or PEP for the outlet portion of the pipe.
On pink sheet: Tabulate concrete pipe in the space (Pipe _____ + ____Aprons). Tabulate CMP or PEP in the space (Flume ______), but revise this space as (CMP/PEP ______ + ___Apron) or (Half-round Flume_____).
The flowline of half-round pipes should be approximately 1 m below natural ground at its terminus. This allows a natural scour hole to develop.
RF-14 type 3 pipe connectors must be noted in Remarks.

Type 1502
Note that the location point is at the inlet. This culvert is generally used in a side ditch.
If CMP is used, need type "A" diaphragm.

Outlet structure not required.

Type 1504

Type 1102 is similar except it does not have a half-round flume.

Teed pipes are generally not recommended except in a side ditch outside the clear zone.

Type 1601

Unclassified pipes are used under unpaved sideroads and entrances. See type 1101 for paved roadways.

Note that the length Lt. & Rt. is to end of the pipe section, not to the end of the aprons.

Type 1602

Use when a bend under an unpaved road is needed. See type 1201 for a similar culvert under paved roadways and 1401 for sideditch letdowns.

Unclassified pipes are used under unpaved sideroads and entrances.

Tabulate bend in the Remarks space.

Type “A” diaphragms are not required when type 1602 is used under a roadway since “piping” is much less likely due to the length of pipe under fill and possible better compaction of bedding and backfill.

Typical 4304 and 4311

Typical 4304 should be used for all culverts where the calculation point is between the subgrade and the hinge point. Typical 4311 is used only when the calculation point is below the hinge point and when the culvert project is the only work being done, i.e., the existing foreslope will be changed only in the vicinity of the culvert. 4311 (and dimension W) should be specified in the Remarks column on the pink sheet. Typically, W may be given as three times the culvert width.